# Uncertainty in Vector Winds

- Vector winds have a speed and direction

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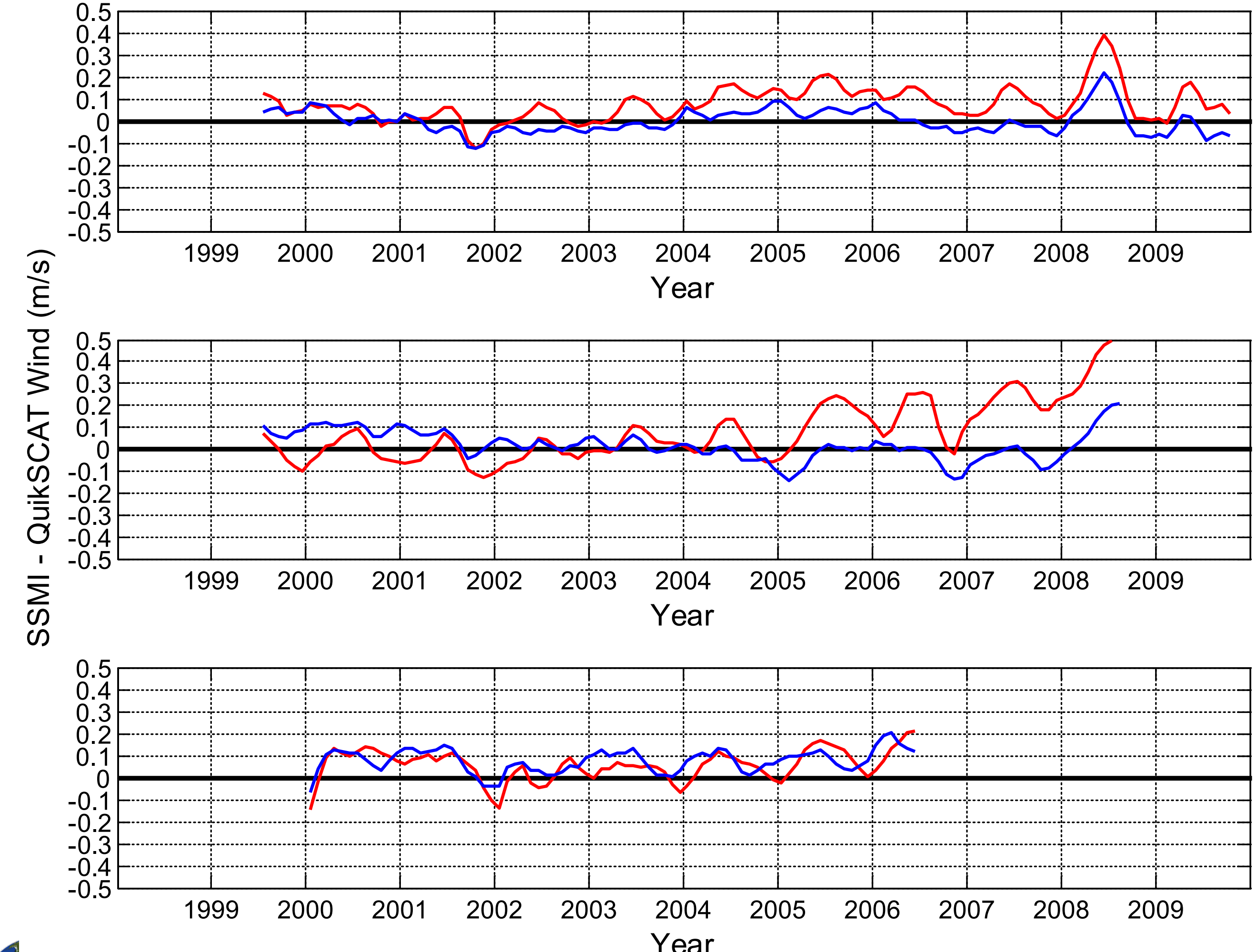
# Combining Satellite and In Situ Systems

- Satellite systems rarely have absolute calibration
  - If they do have it, it applies to backscatter or radiance
  - Rather than desired geophysical ocean variables
- Satellites usually have relatively stable calibration (compared to in situ)
  - Meaning stable in time and spatial location
  - However, the geophysical calibration of satellites is often empirical
    - Calibrated to NWP or in situ data
- For climate applications, such as decadal changes, the calibration must be quite accurate
  - Careful definition of variable (e.g., equivalent neutral winds)
  - Careful adjustment of in situ data to same definition
  - Removal of relative biases in each source (platform) for situ data
  - If the apparent bias is outside expected bounds, it indicates a problem with the data or physical assumptions

# Corrections to satellite data improve stability

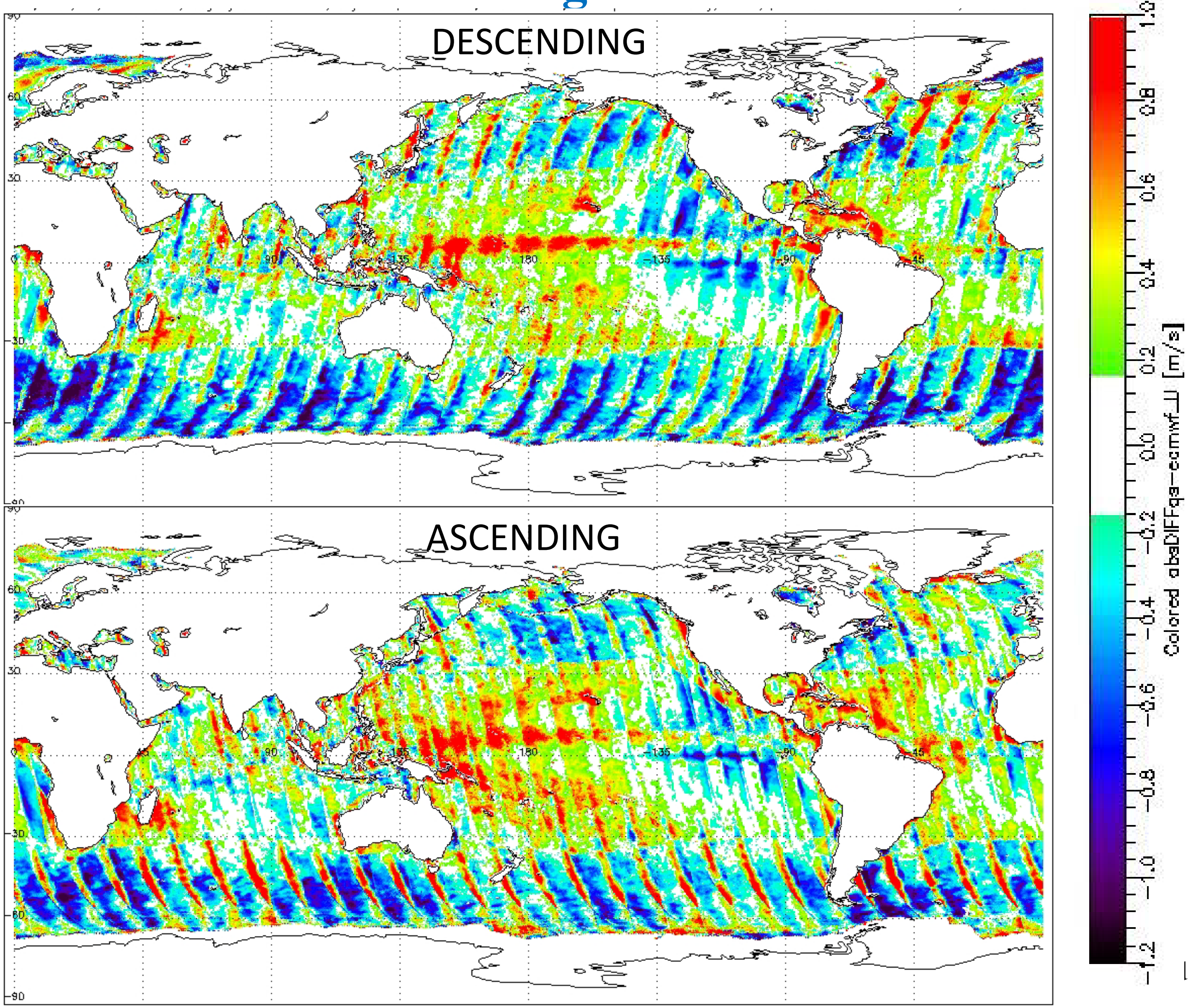



- For three different satellites with SSM/I instruments
  - Relative to buoys
  - (SSMI v6 in red; QSCAT v7 in blue)
- SSM/I (two different satellites with SSMI) Minus QuikSCAT Wind Speed
  - Differences are not consistent
- Clear trends in differences: bad
- Fixed in next version
- Graphics courtesy Frank Wentz

# Consistency Across the Swath

- The same tests are done across a swath of observations
  - To make sure the pdfs are similar for each column across the swath
  - To make sure the fits to comparison data are similar (within differing noise characteristics).
- The next example shows this problem
  - Across swath differences were used to identify a pointing error in the instrument
- Other issues include
  - systematic errors in the hot sample or cold sample for radiometers
  - Emissive antennas (e.g., SSMI/S) – bad if emitting in the band being observed

# OSCAT Zonal Wind Bias w.r.t ECMWF
## Average difference over 2011

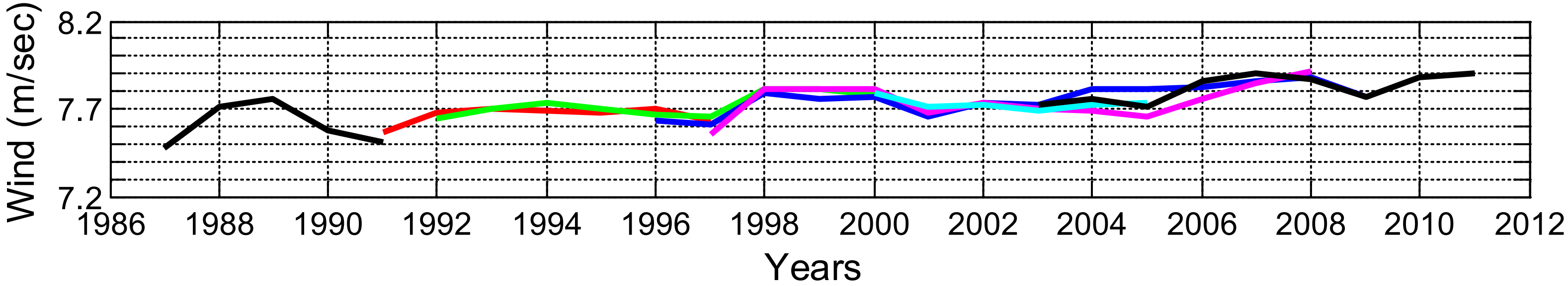



Errors shown are for JPL processing with rain flagging but no rain correction, KNMI and ISRO wind retrievals have similar biases.

Errors are most noticeable for zonal components of the wind. Biases in meridional components and wind speeds are much smaller.

# Examples of success

- Change in Tropical Pacific Winds  (Wentz, Xie and others)




  - Shows a trend of roughly 0.1 m/s/decade!
  - Builds on a great deal of comparison data, collected over long times, and overlapping satellite records (inter-calibration)

# Stability of Calibration

- A relatively small number of very high quality observations can be used to test calibrations
- They must be sustained
  - To test and/or maintain the calibration
  - There have been several examples where drifts in calibration appear to be trends in time series
- Other sensors are needed to provide better space/time coverage

- **Historically the observational community has said: The combined in situ and satellite system is needed to maintain a global network for surface observations**
  - To identify problems & for many applications
- For climate this is a dubious claim because the stability of the in situ observations is often far worse than for satellites (e.g., buoy winds)
  - Overlapping (non-sun-synchronous satellite observations are needed)

# Wind Sensors

- On the previous page, many wind sensor are shown (the list is not complete)
  - Active, passive, and passive polarimetric techniques
  - Fortunately, all are now calibrated to equivalent neutral winds at 10 meters
  - Most only provide wind speeds (altimeters and most radiometers)
  - Some provide scalar wind speed and direction (scatterometers and the WindSat passive polarimeter)

- Lots of sensors for speed intercomparison
  - Few for direction (or vector components)

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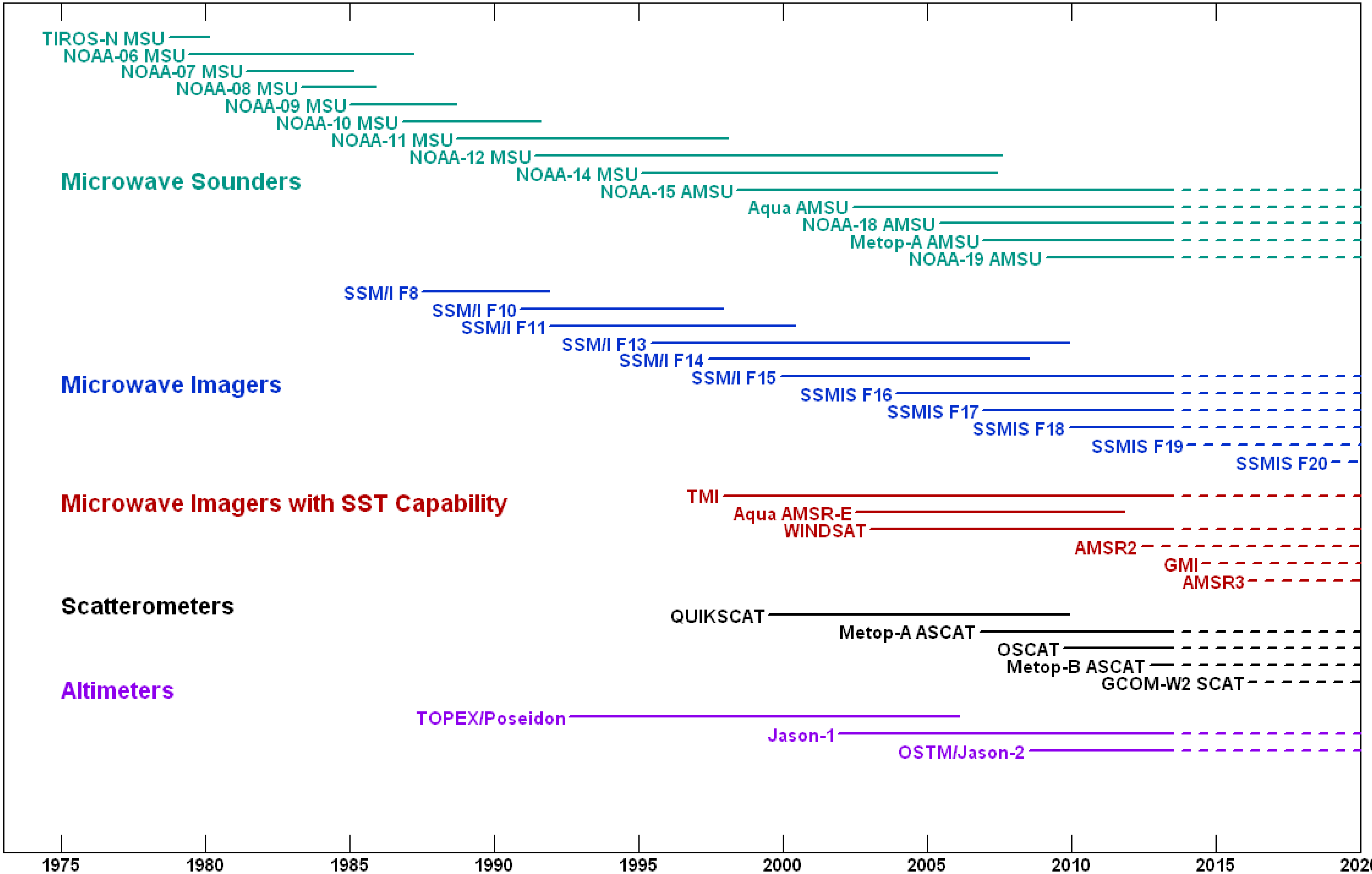
# Inter-calibration




- Graphic from Frank Wentz (Remote Sensing Systems

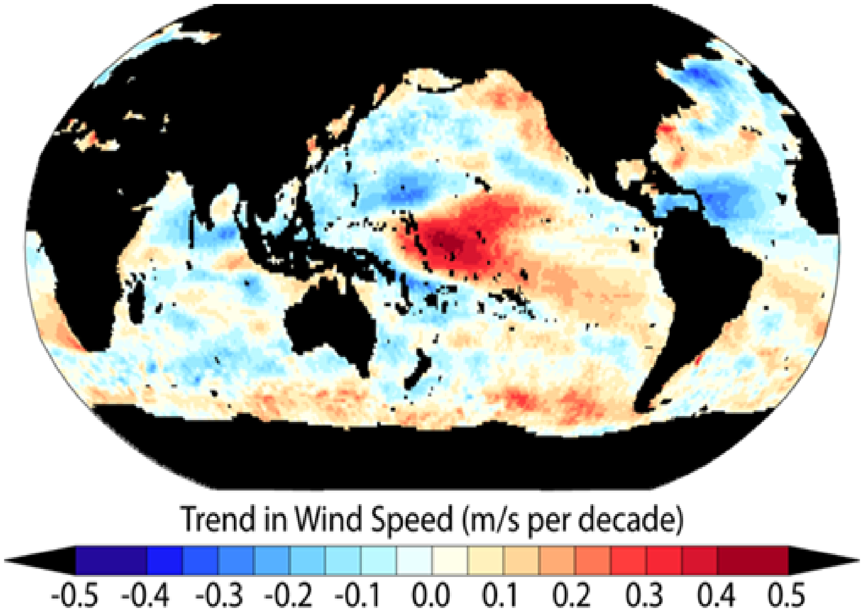
# Several Approaches

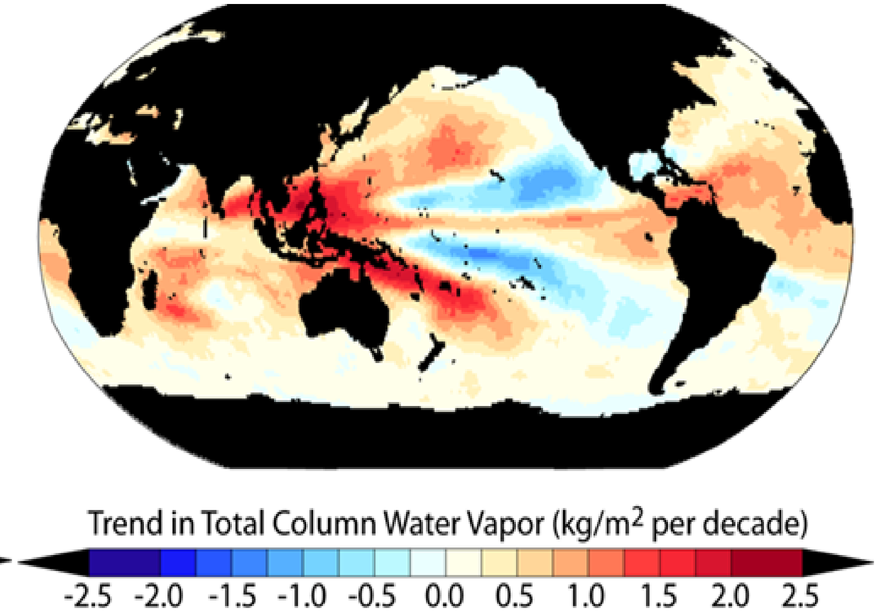
- Comparisons of geophysical observations to NWP can be useful for spotting changes in behavior (provided they are not coincident with changes in the model physics)
- Compare all sensors to ground 'comparison data'
  - In situ observations are not 'truth' – they are not perfect observations
  - This is sometimes a good approach for assessing stability of accuracy
  - But is only good for conditions for which there are sufficient observations (i.e., relatively typical conditions)
  - Comparison data could be
    - in situ observations of the geophysical variable of interest
    - Stable targets for looking at consistency of fundamental observations (e.g., radiance, backscatter, or travel time)
    - Multiple satellites (need at least three pairs)
- Checks for consistency of fundamental observations are essential for long term climate (a GCOS observing principle)
  - Therefore satellites should have overlapping periods of operation

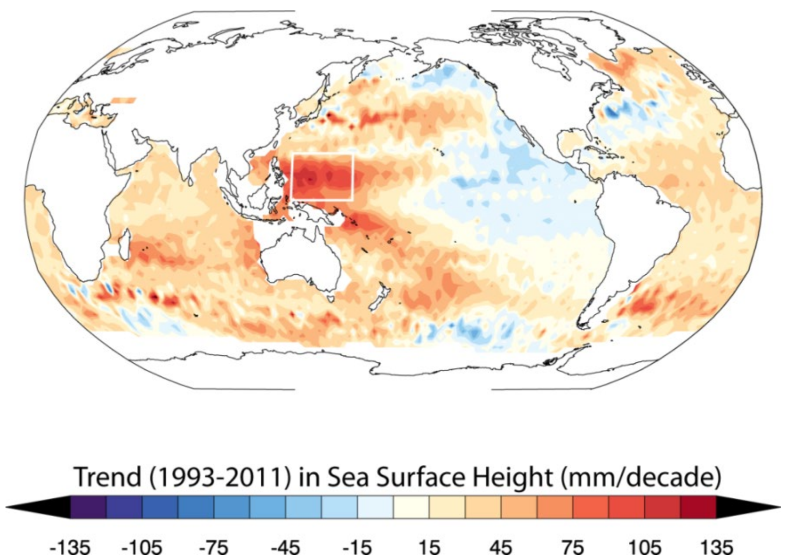
# Typical Problems

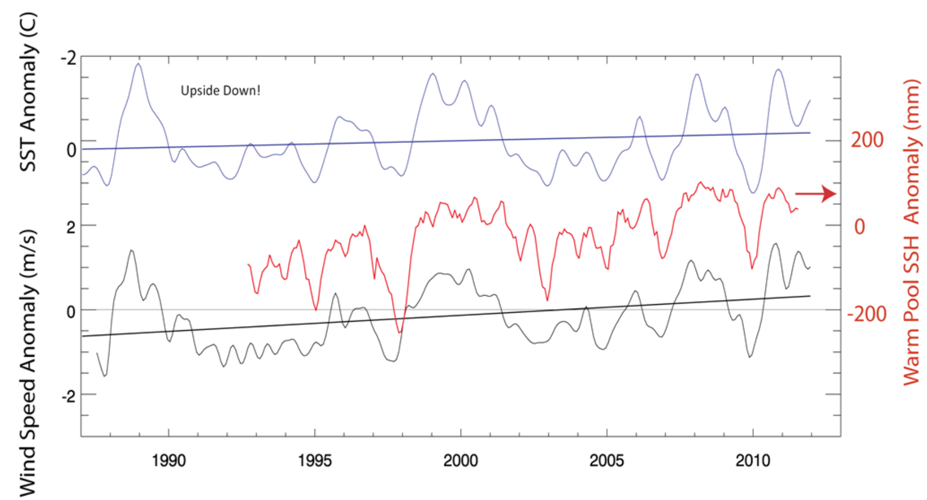
- Sometimes coincidence is ignored when constructing histograms!
  - This is a disaster if the two data sets are measuring different spaces
  - Diurnal cycle is also a problem
- Some researchers don't read the definitions (e.g., wind vs. equivalent neutral wind). If the definition is not referenced, don't have confidence in the work. It might be OK, but this would not be a good sign.
- Most data providers cater to users (for good reason)
  - Users often cringe a changes in calibration
  - Therefore data providers delay upgrades to calibration
  - This slows the convergence to excellent calibration
  - Most users don't need climate-quality calibration, and contribute to the difficulty in achieving such calibration by not wanting to deal with change
    - E.g., EUMETSAT and NASA rarely update calibrations

# Quarter-Century Trends from Satellites




Graphics from Frank Wentz (Remote Sensing Systems)

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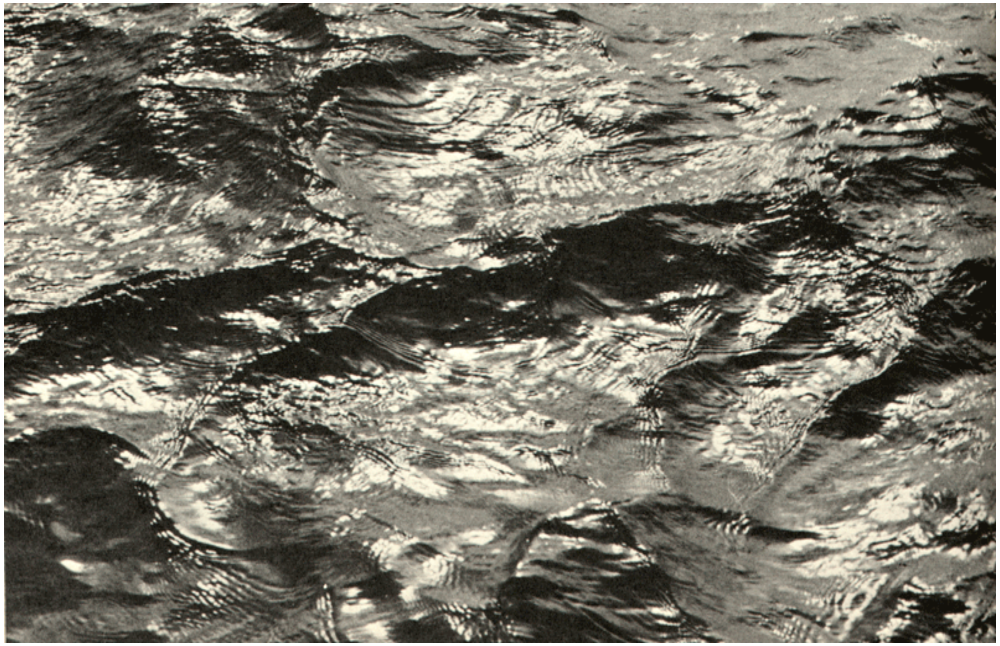
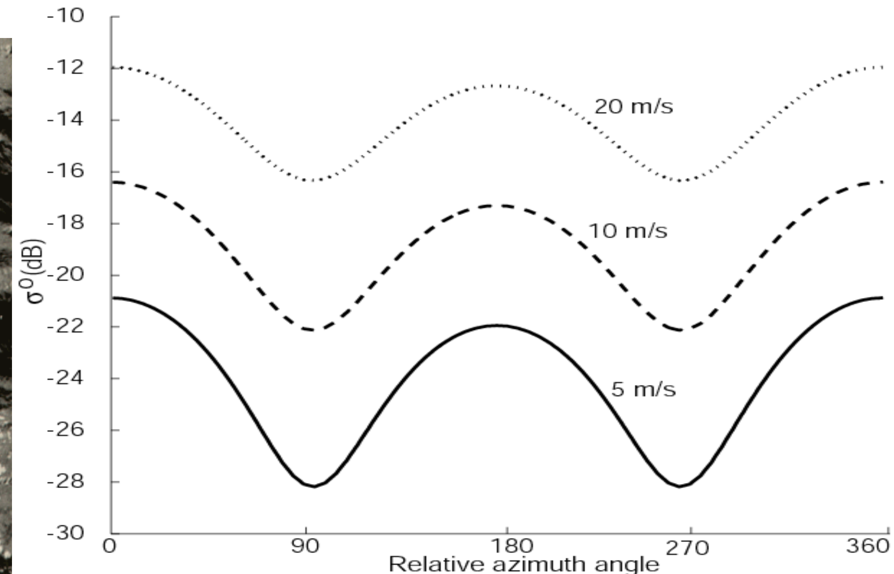
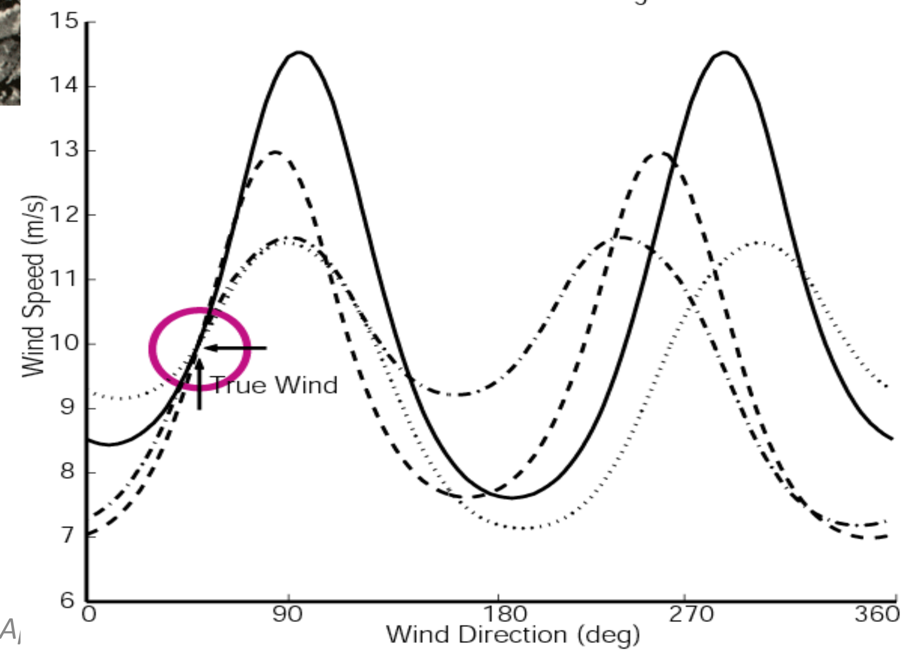
# Wind Measures of Uncertainty

- For older scatterometer data sets, observational characteristics have been described in terms of speed and direction
  - In part because of
    - The retrieval technique designed in terms of speed and direction
    - Flaws in the retrieval technique
- With current retrievals, it is sometimes more practical to specify errors in terms of vector component errors
  - Much easier to apply
  - Much more useful for estimating errors in curl and divergence
- We will likely see observation goals expressed in vector component errors

# Backscatter is a function of speed and direction

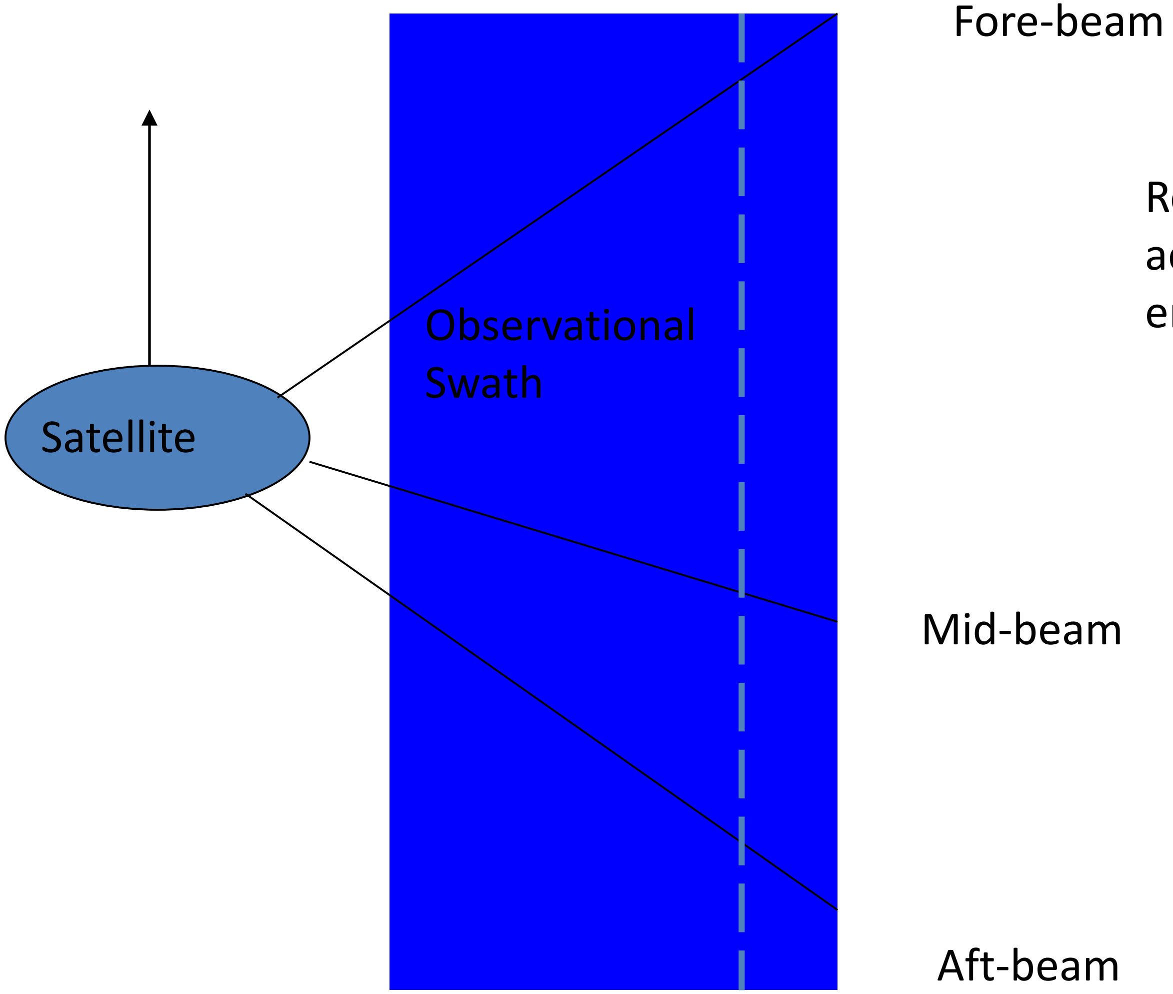





- A geophysical model function mimics how the backscatter changes as a function of wind speed and direction.
- The solution for speed is dependent on the solution for direction.
- Consistency in directional accuracy suggests a greater likelihood of reduced across-swath dependency in the accuracy of speed.

# Fan Beam Design – Typical of ASCAT

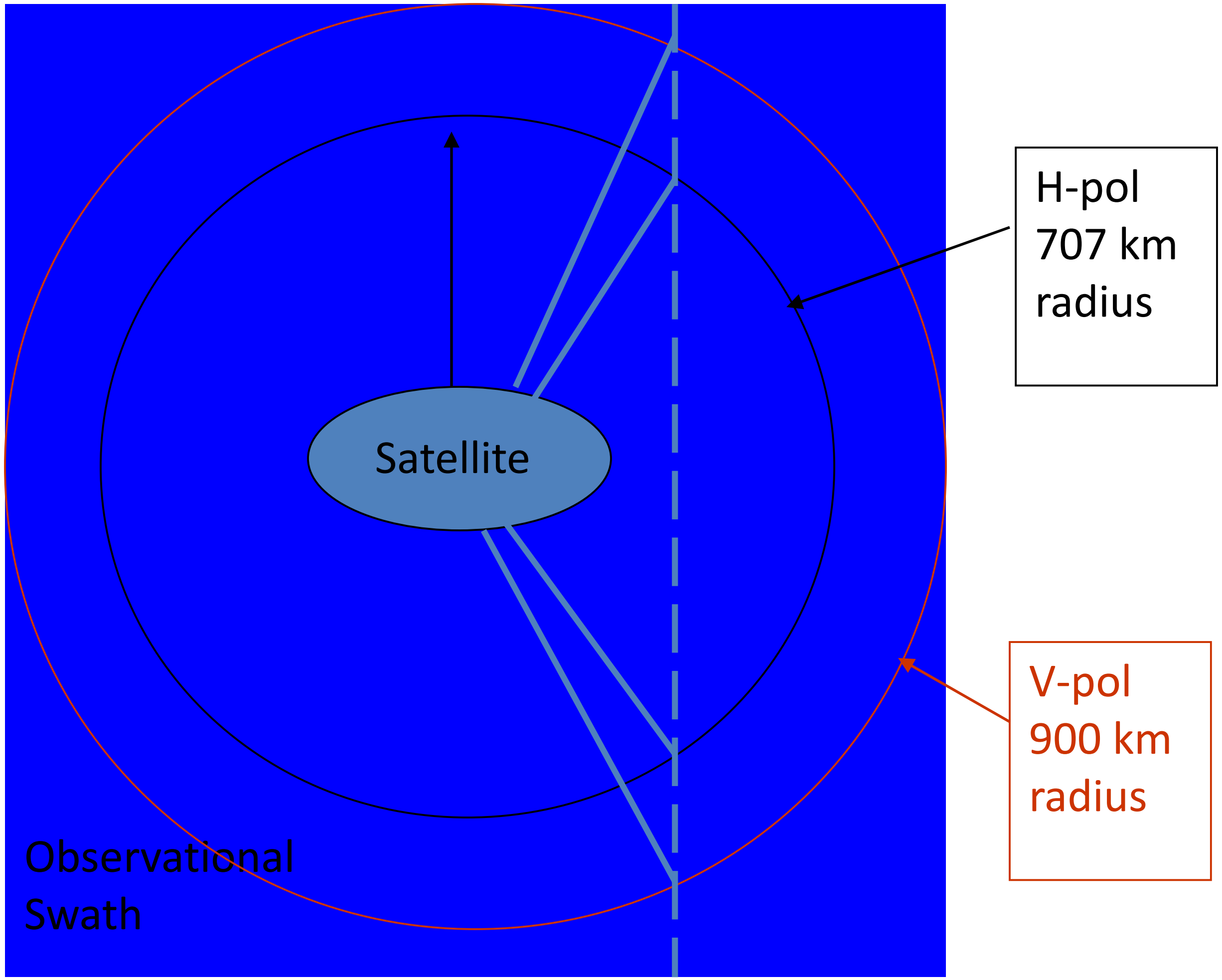



Results in relatively little across-swath dependency of errors in speed and direction

# Conical Scanner

Better coverage in space and time

At the expense of similarity in error characteristics across the swath



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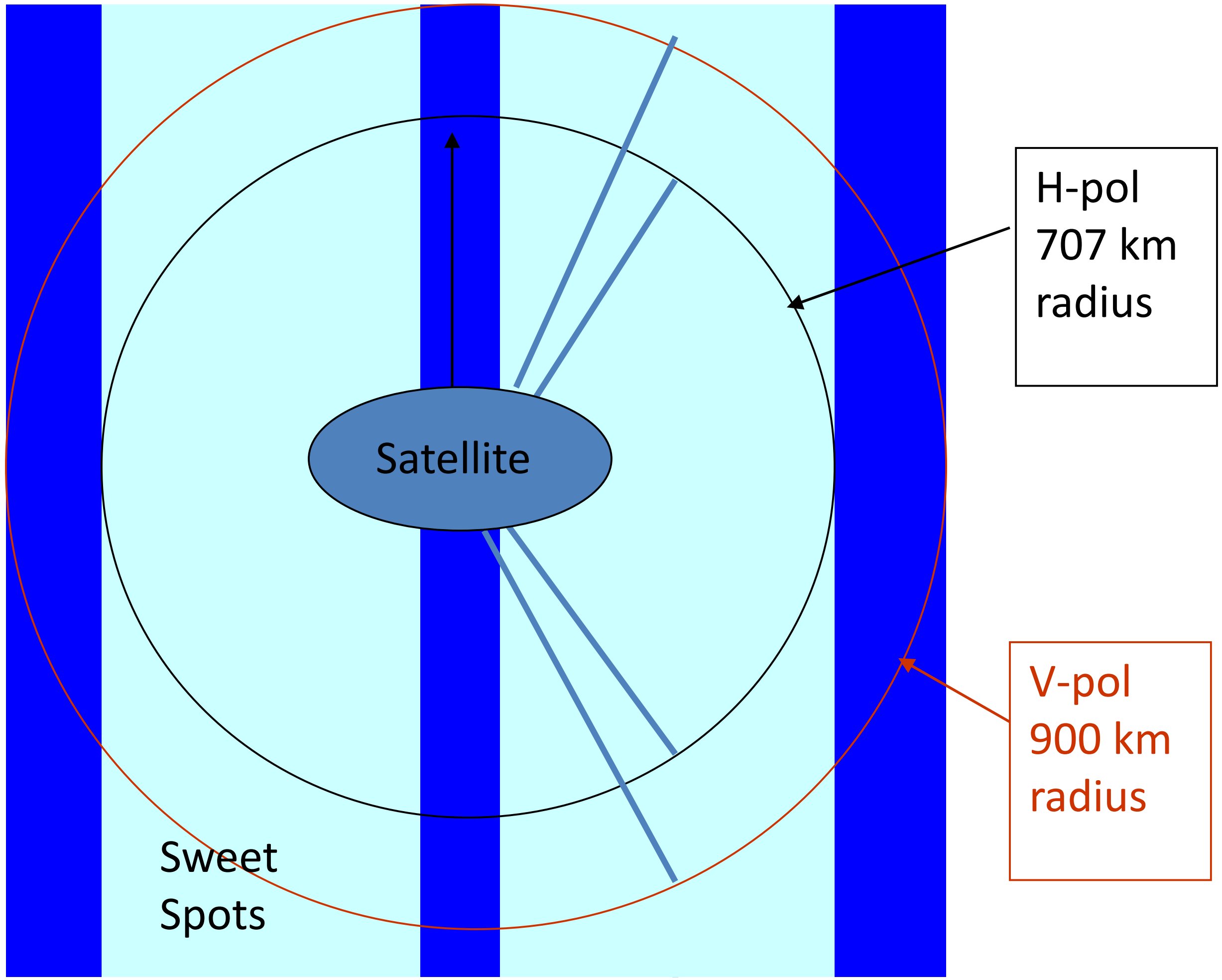
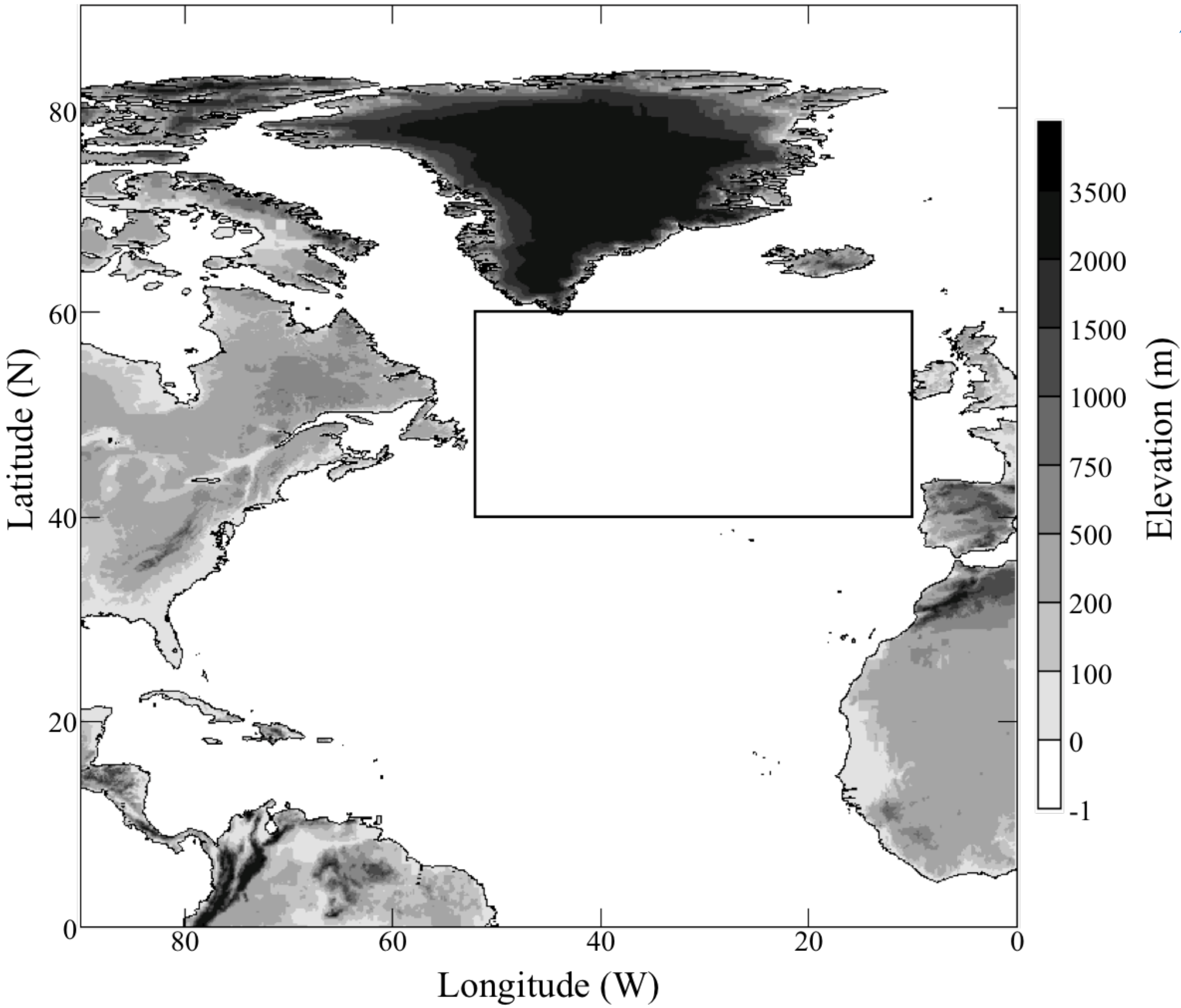


# Intercalibration of Curl

- Curl is very important for vertical transport & mixing in the ocean
- Divergence is very important for vertical transport & mixing in the atmosphere
- Vorticity spectra are analyzed to show consistency of the derivative fields.
- Error characteristics of vorticity are highly dependent on grid spacing of the wind fields, therefore 12.5km products are used for all scatterometers (JPL QSCATv3, JPL OSCAT, KNMI ASCAT)
    - 12.5km products
    - 50km (4 grid cell diameter averaging)
    - Line integral approach to determining vorticity

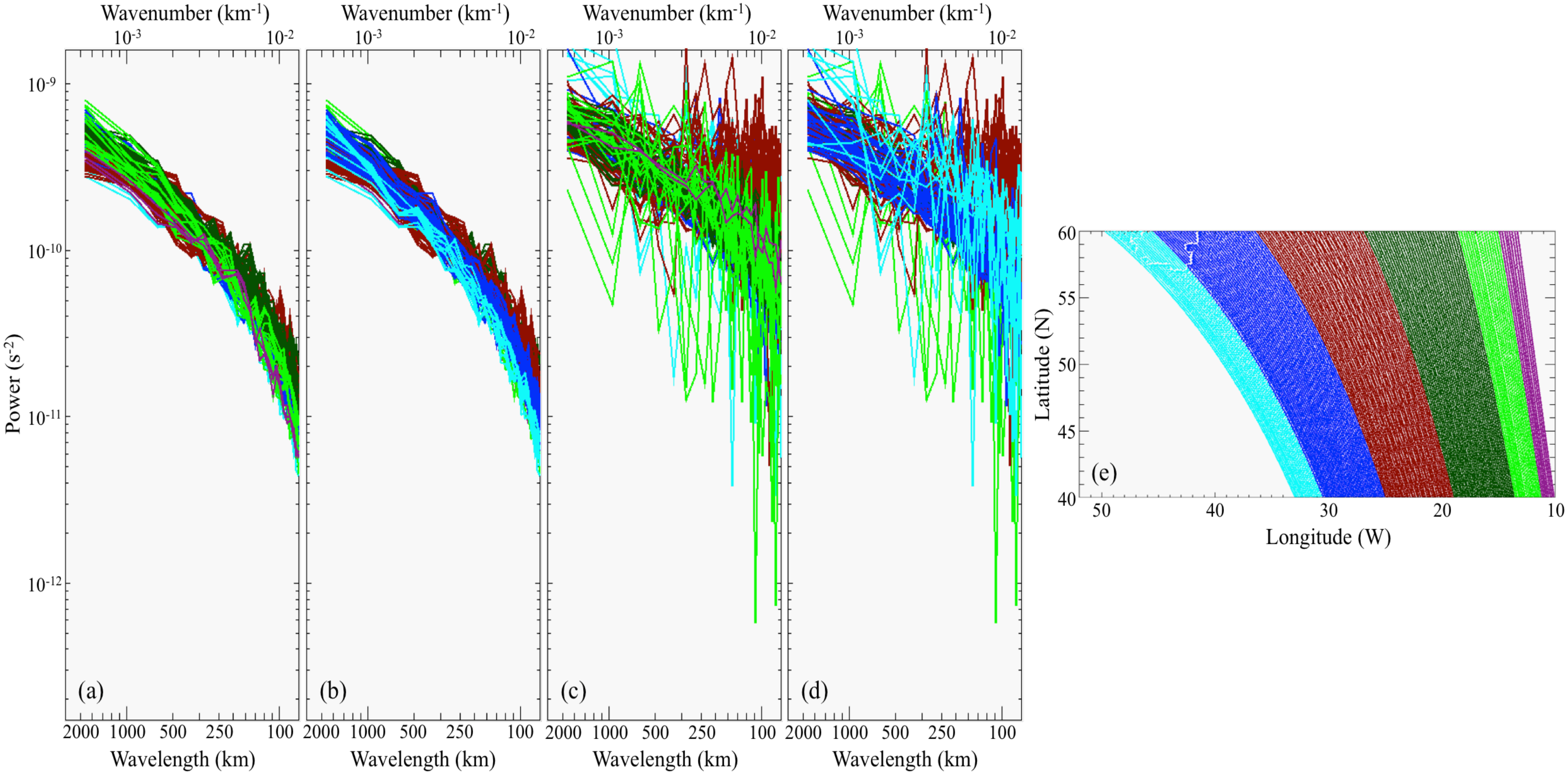
- More details in Holbach and Bourassa (2017)

# Region of Example Vorticity Calculations




- Observations should come from the same region
  - Otherwise difference could be solely due to regional differences in vorticity
  - Time period is Nov. 2009 for QSCAT, Nov. 2009 and 2010 for ASCAT, and Nov. 2010 for OSCAT

# Technique for Determining Winds Matters




- JPL QSCAT v3 (a,b) and JPL QSCAT v2 (c,d).
- Each line represents a power spectra for an individual wind vector cell column corresponding to the across swath locations in (e).
- JPL v3 processing is much better than v2!

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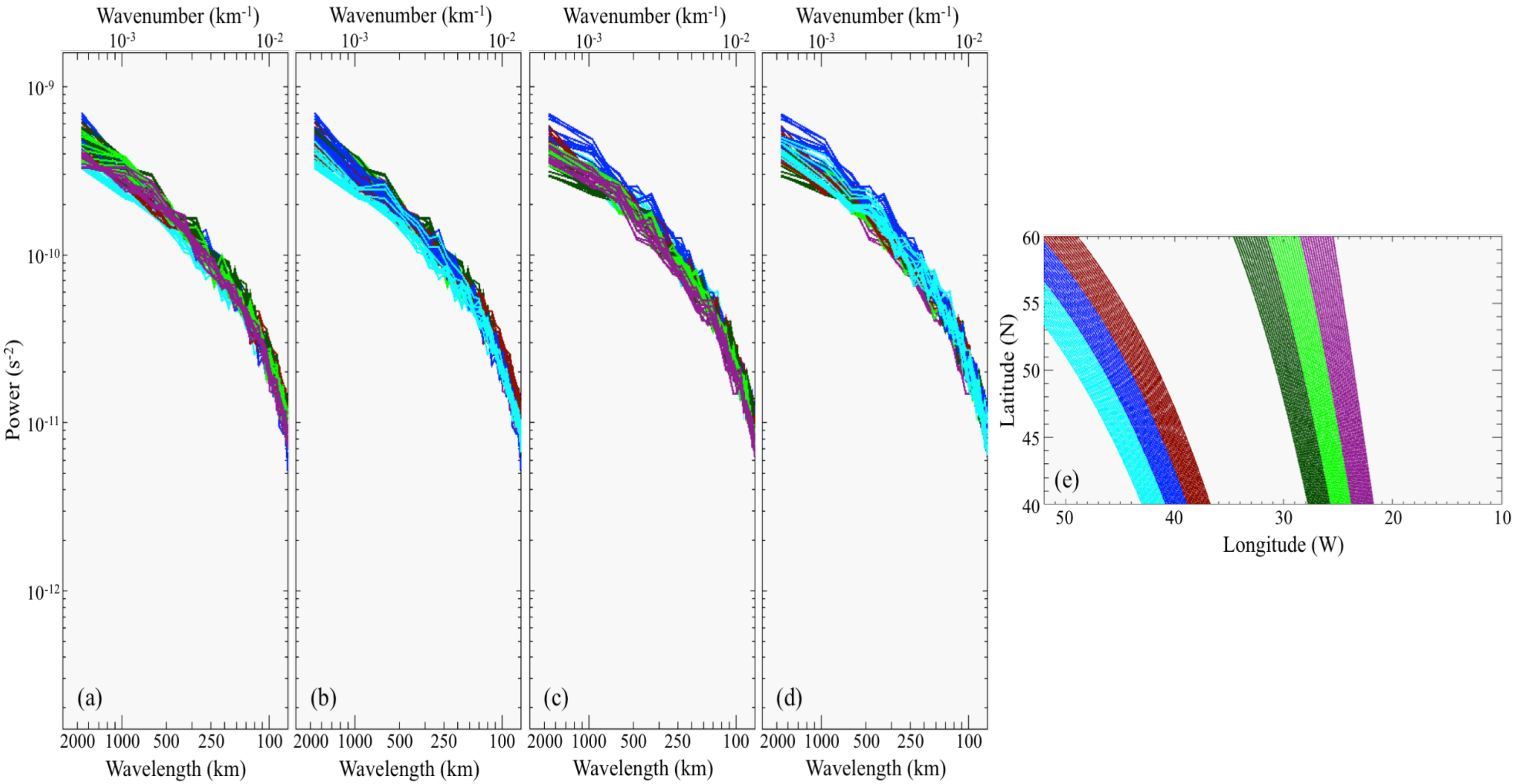
# ASCAT for Nov. 2009 and 2010




- ASCAT-A winds in Nov. 2009 (a,b) and Nov. 2010 (c,d).
- Each line represents a power spectrum for an individual wind vector cell column corresponding to the swath locations in (e).

# Lessons Learned

- Vorticity calculations are sensitive to
  - Grid spacing of the wind product (not shown – but a big deal)
    - Finer grid spacing has a large positive impact
  - The errors in some retrieval algorithms
  - Random errors in the wind products
- Relatively insensitive to systematic errors
  - Hence nice for examining random errors
- Differences between QSCAT, ASCAT, and OSCAT are small when comparing products created with the same grid spacing
  - Product to product differences are substantially smaller than the variability in the annual cycle

# Data

## Scatterometer Data

- COAPS Simplified Daily Satellite Swath Dataset
  - ASCAT-A: 2009-2015
  - ASCAT-B: 2012-2018
  - QuikSCAT: 1999-2009

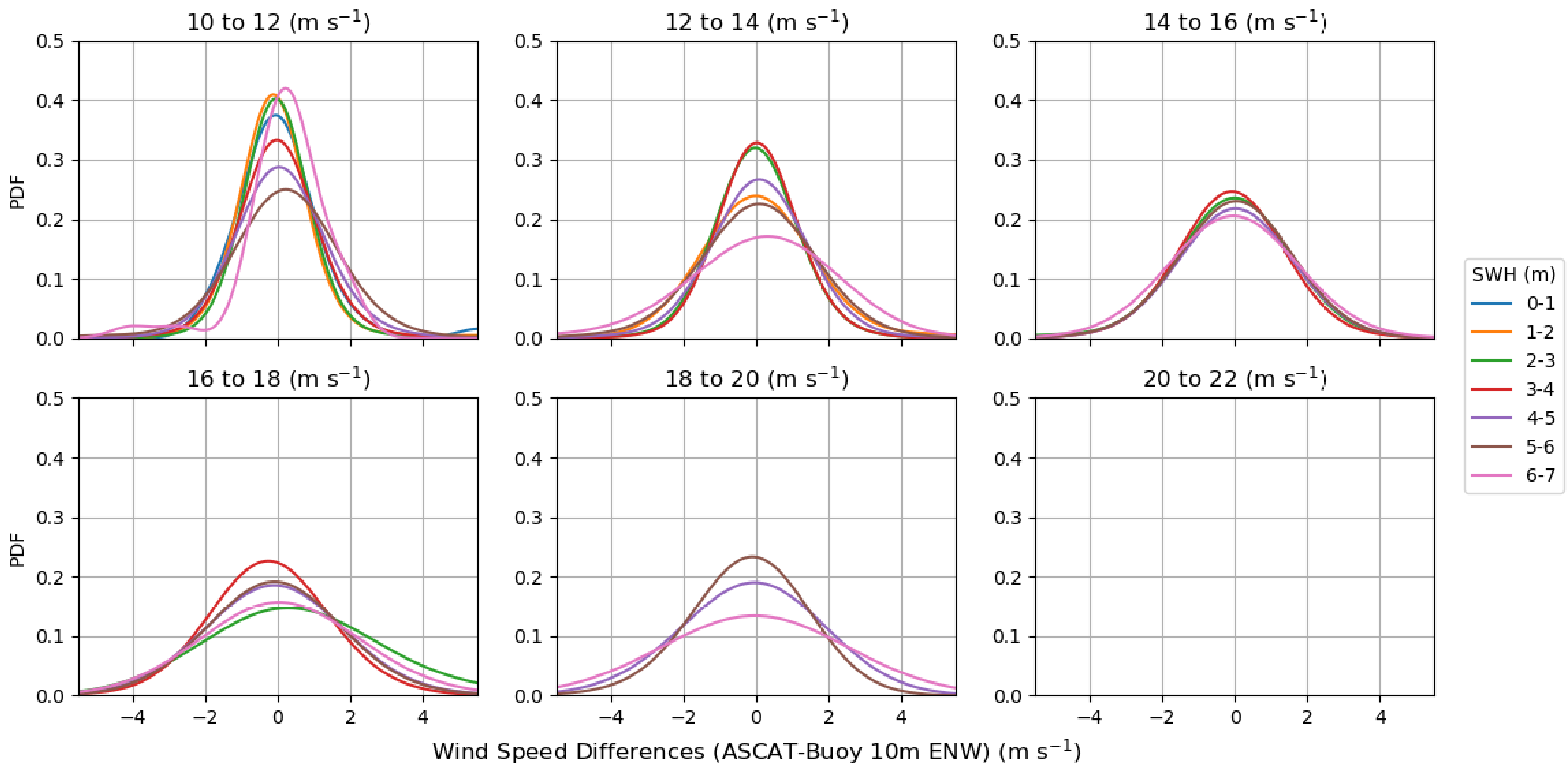
## Collocations

- Buoy data were matched with scatterometer data using a spatial threshold of 25 km and a time threshold of 30 minutes.

## Buoy Data

- NDBC Moored Buoy Network
  - At least 25 km from shoreline
  - At least 1000 ft. depth to seafloor
  - Measurements include:
    - 8 minute averaged wind speed and direction
    - Significant wave height
    - Air temperature
    - Barometric pressure
    - Sea-surface temperature

# Results: Differences binned by SWH and separated by Scat. Wind speed (ASCAT)

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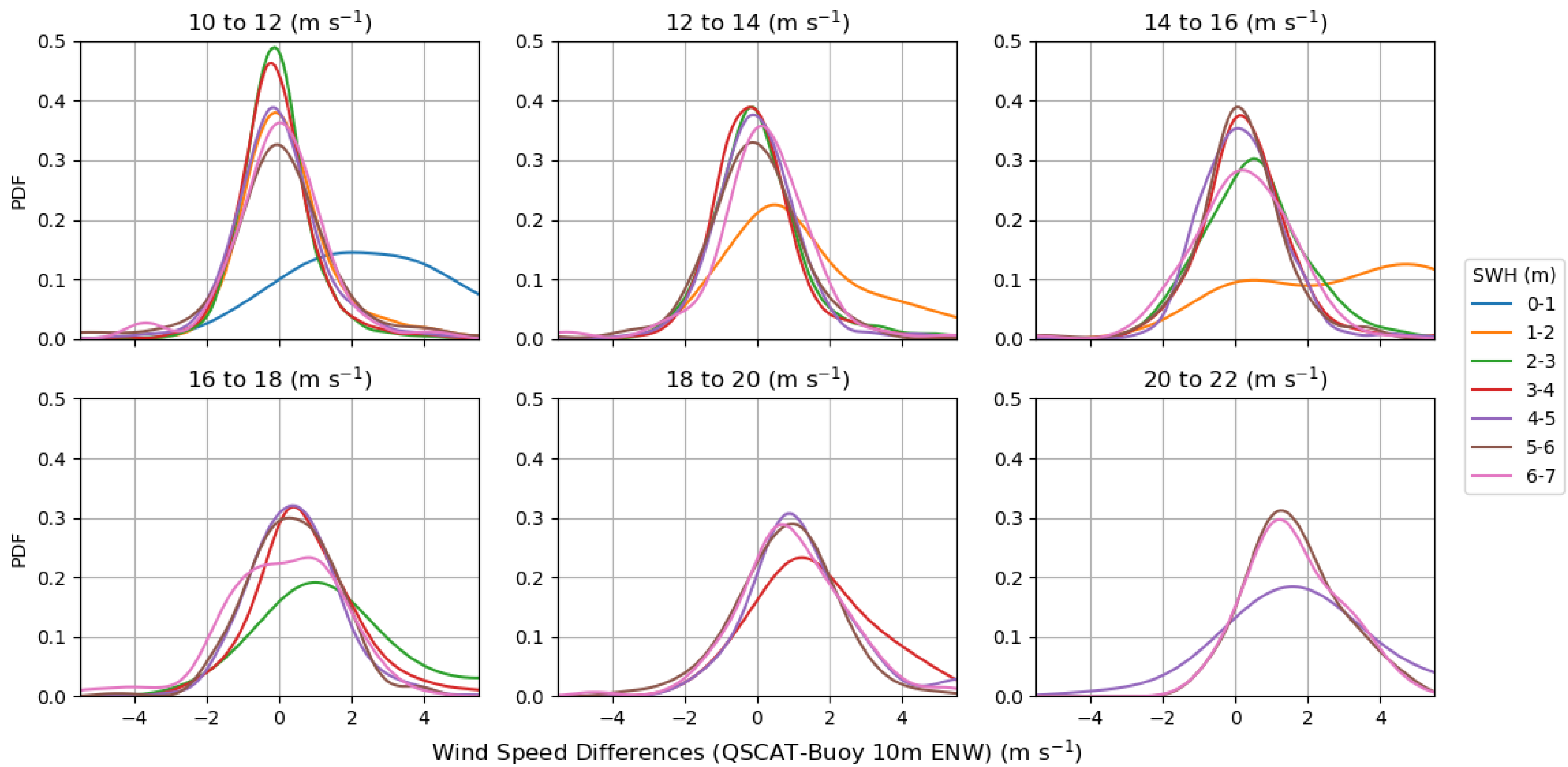
# Results: Differences binned by SWH and separated by Scat. Wind speed ranges

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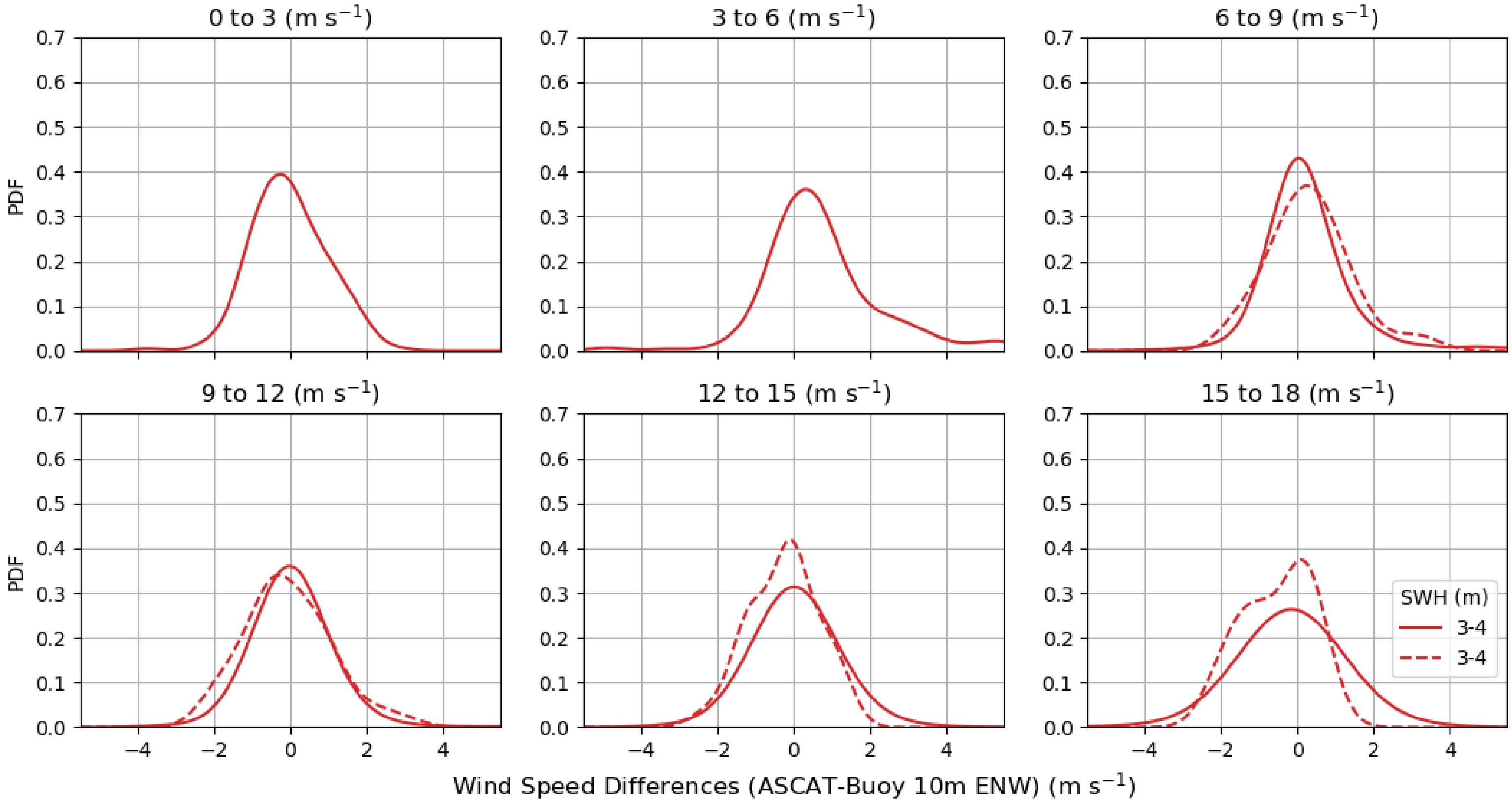
# Results: Separated by Anemometer Height

## ASCAT, SWH=3-4m

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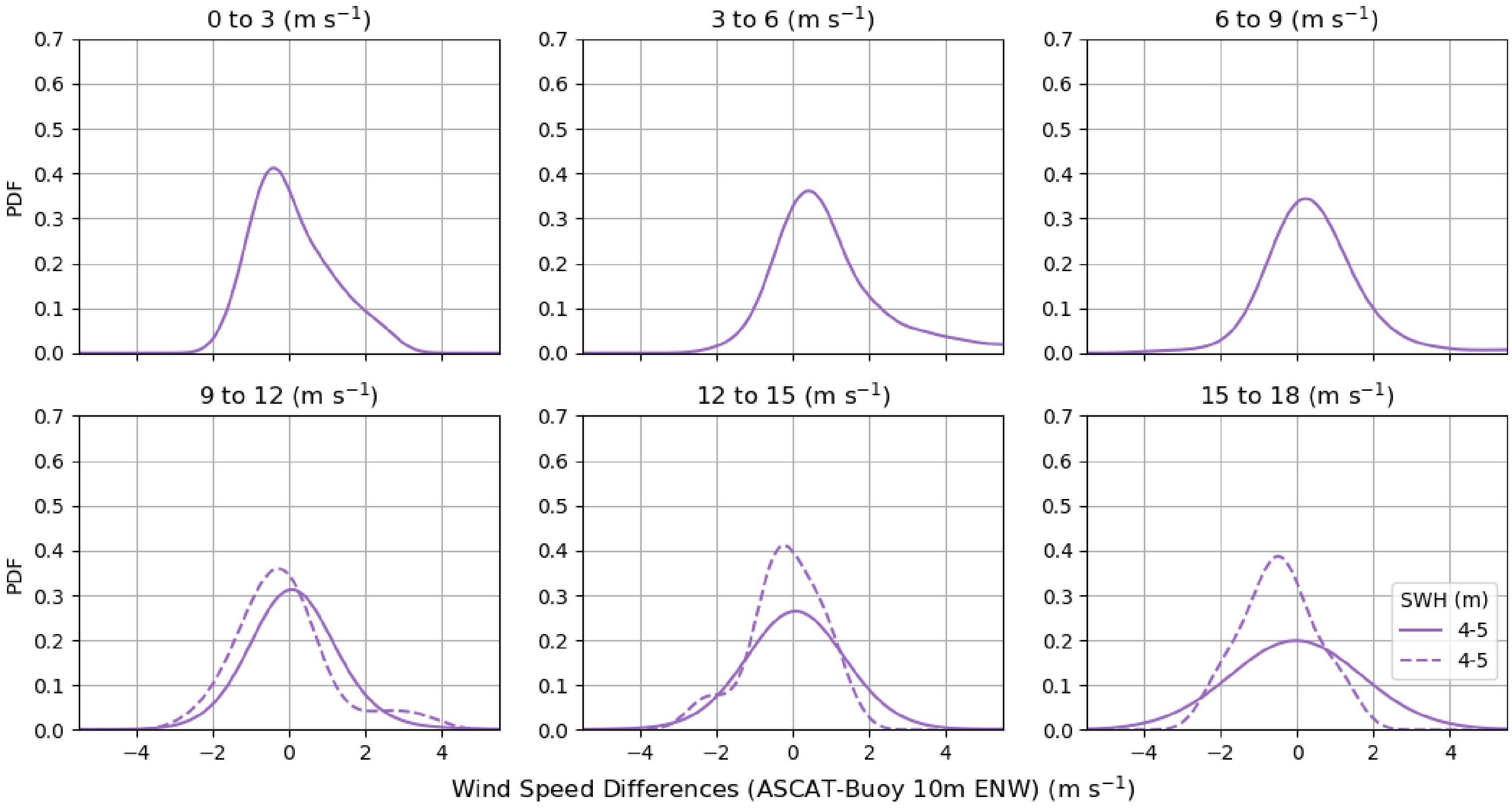
# Results: Separated by Anemometer Height

## ASCAT, SWH=4-5m

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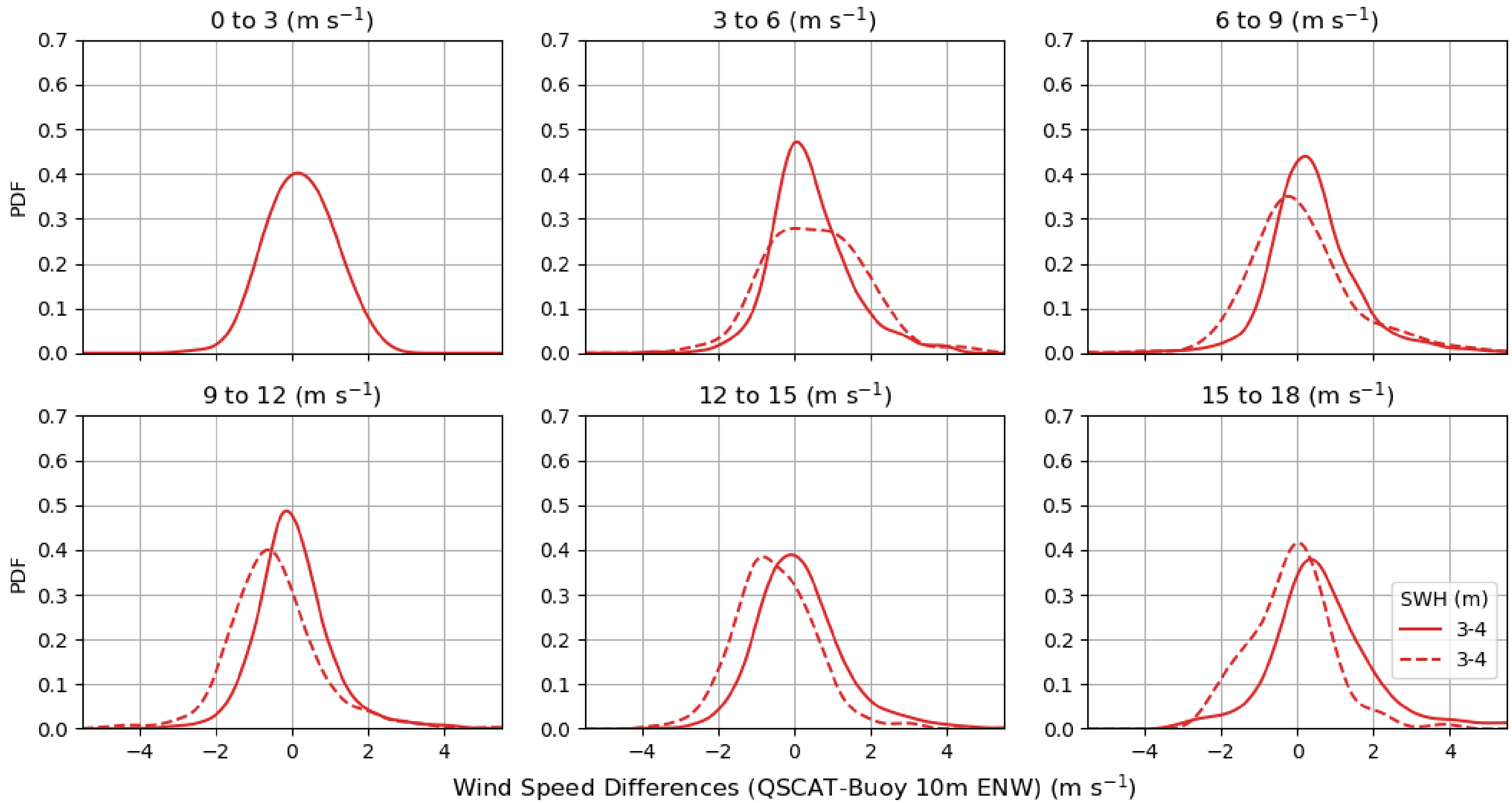
# Results: Separated by Anemometer Height

## QuikSCAT, SWH=3-4m

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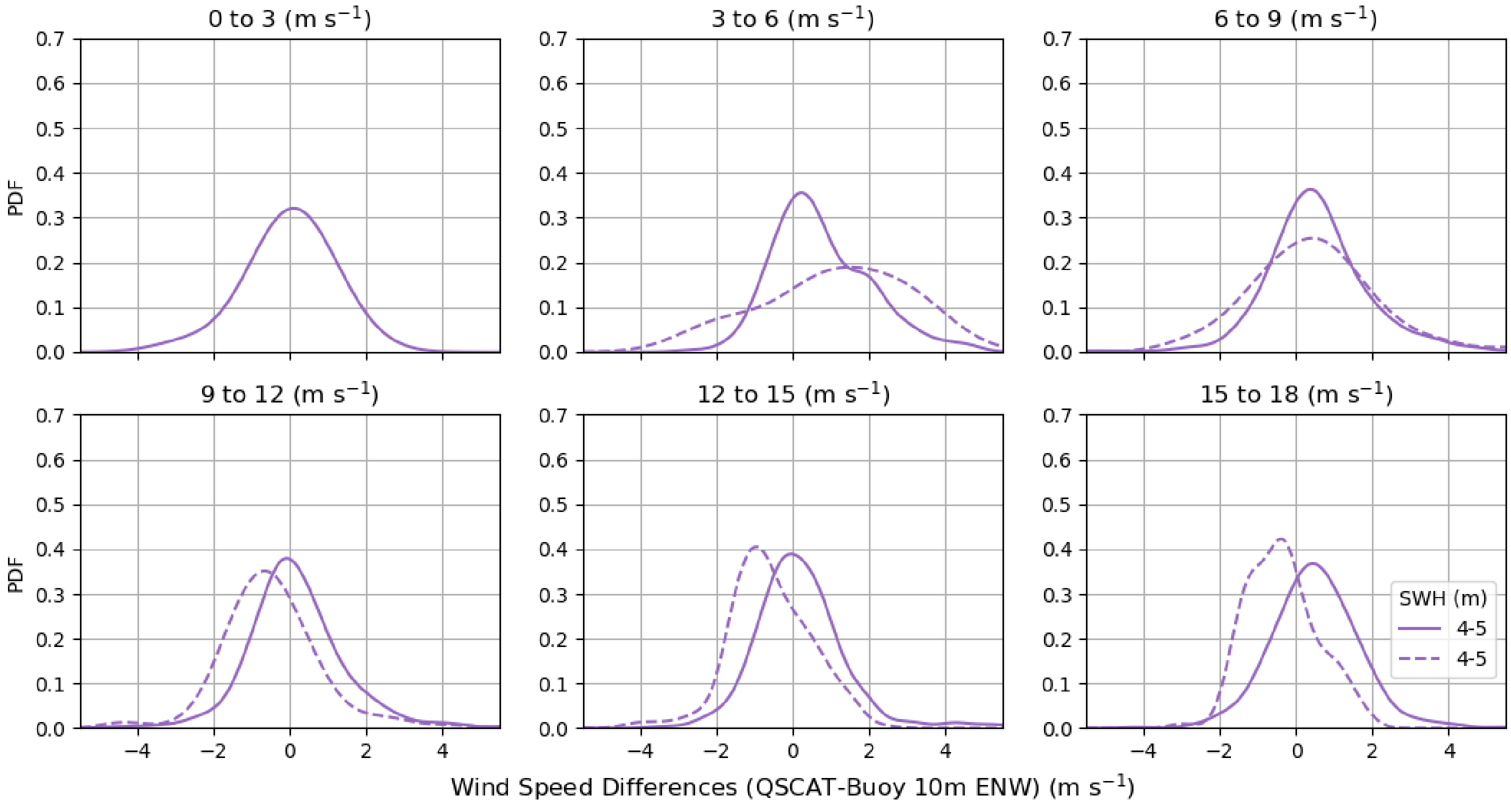
# Results: Separated by Anemometer Height

## QuikSCAT, SWH=4-5m

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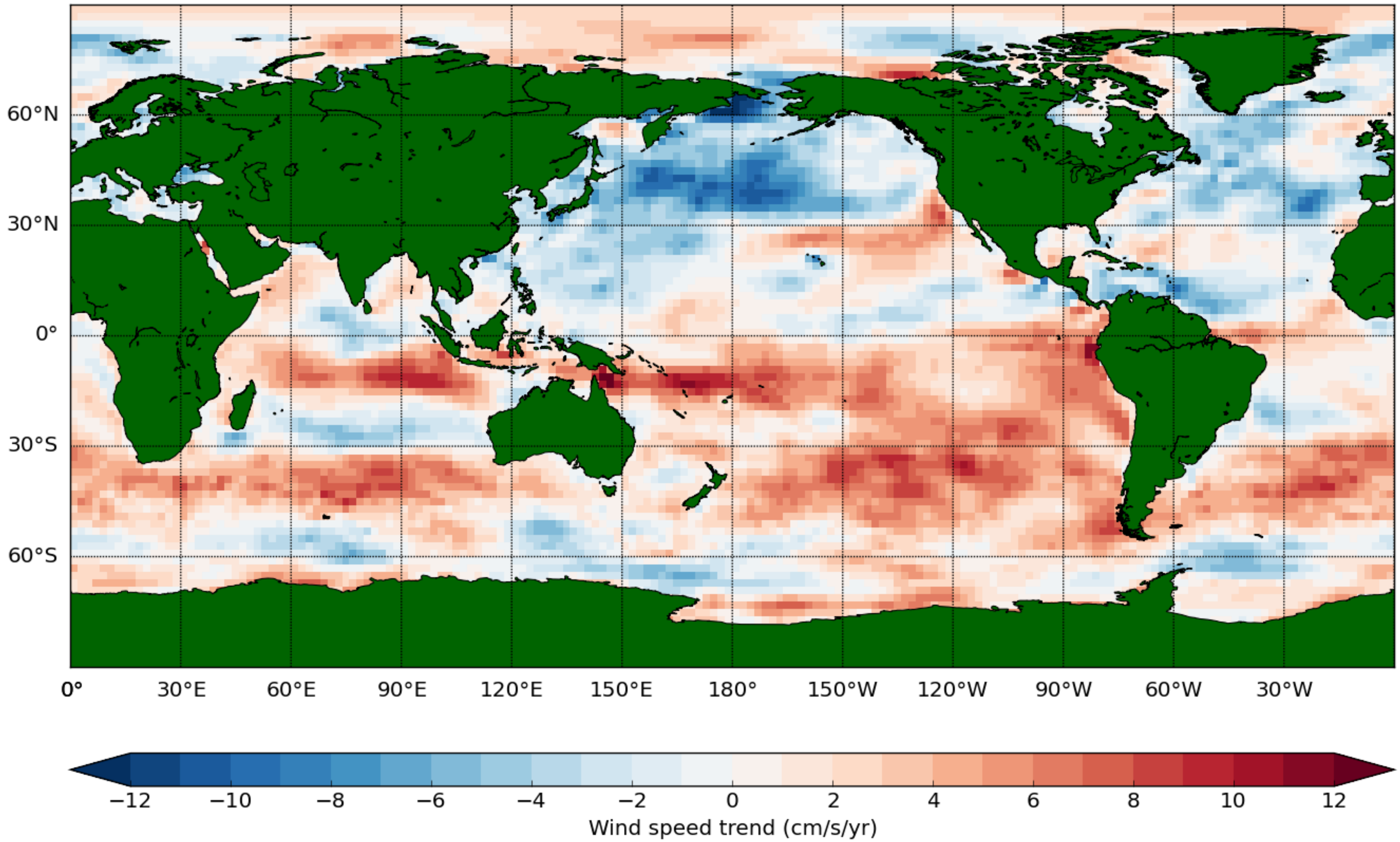
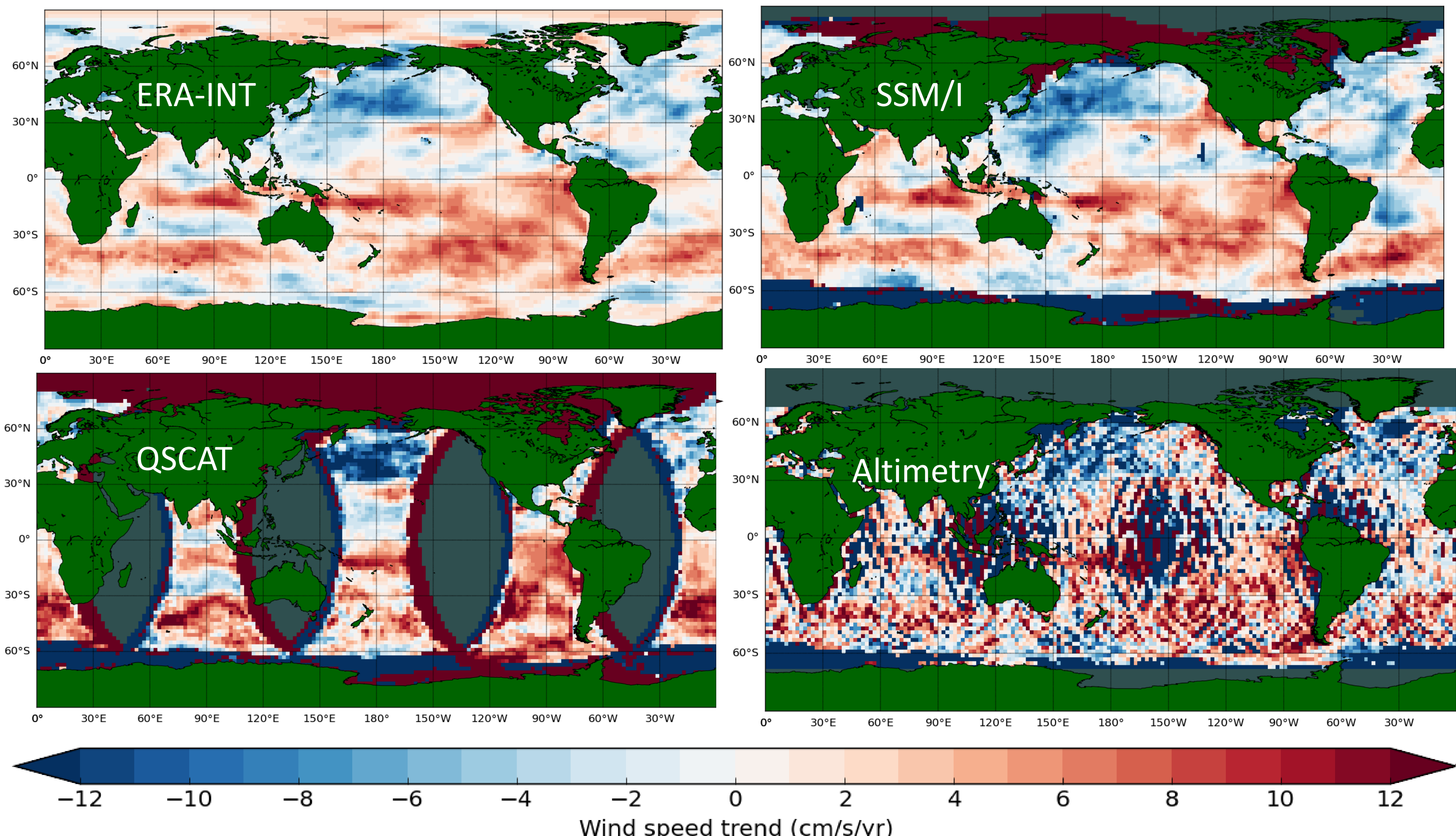
# Sampling Limitations for Extremes

- Trends in the mean winds are ‘relatively easy’ to determine from scatterometer observations
- However, trends in higher percentiles are quite challenging
- We sample the ECMWF’s ERA-Int winds to test the importance of sampling
- For three types of sampling during the QuikSCAT period
  - QuikSCAT sampling
  - Altimeter Sampling
  - SSMI (multiple satellites sampling)
- Examined the mean, $90^{th}$ percentile, and $99^{th}$ percentile wind speeds
  - Restricted to times within 1.5 hours of the ERA-Int winds
  - To reduce inconsistancies with sampling of Diurnal winds
  - Observations are synthetic (matching ERA-Int) to reflect purely sampling related problems (not observational error)

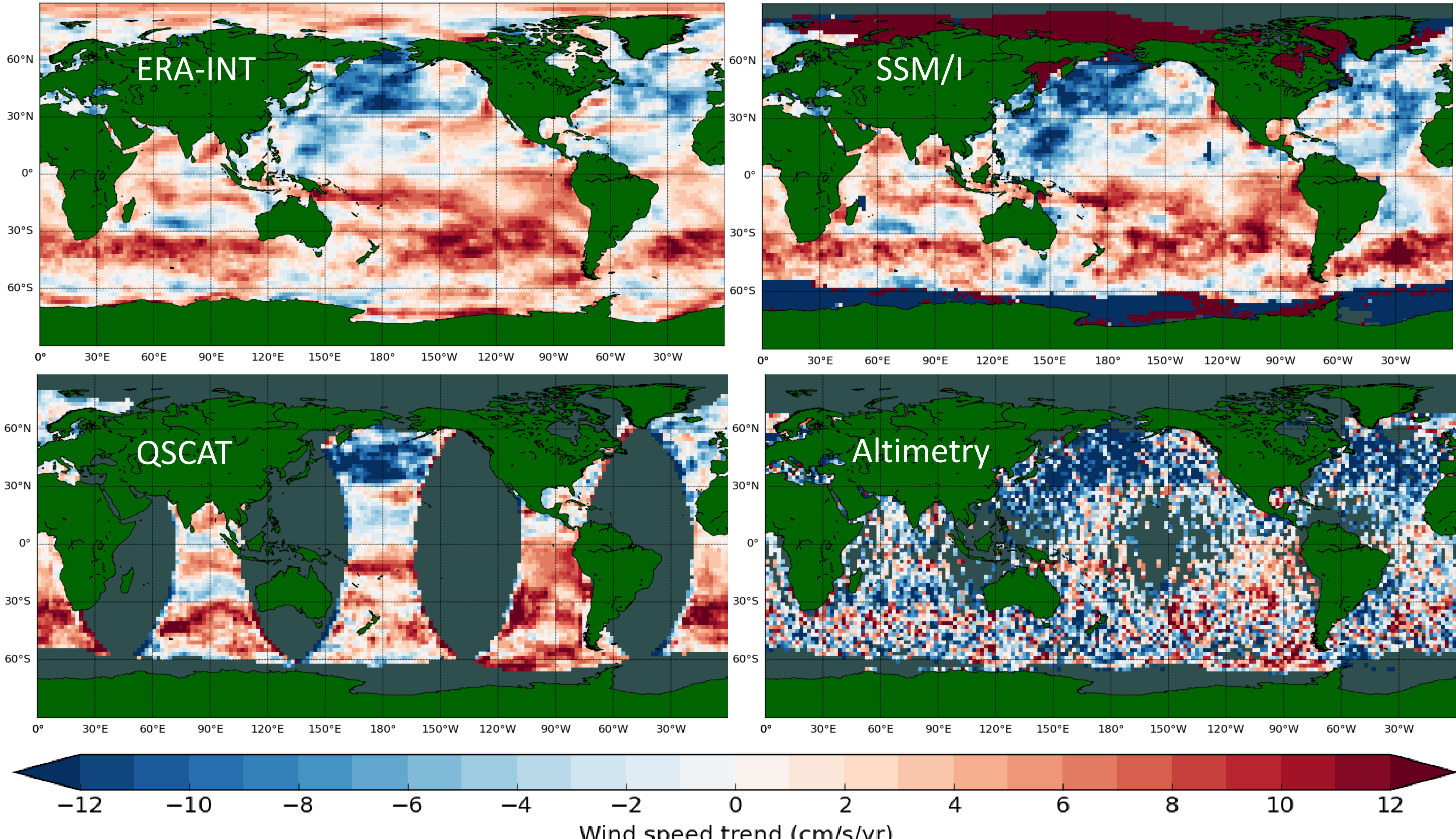
# ERA-Int Trends in Wind Speed During QSCAT Period



# Comparison of SSM/I, QSCAT, and Altimetry Means



# 90th Percentiles

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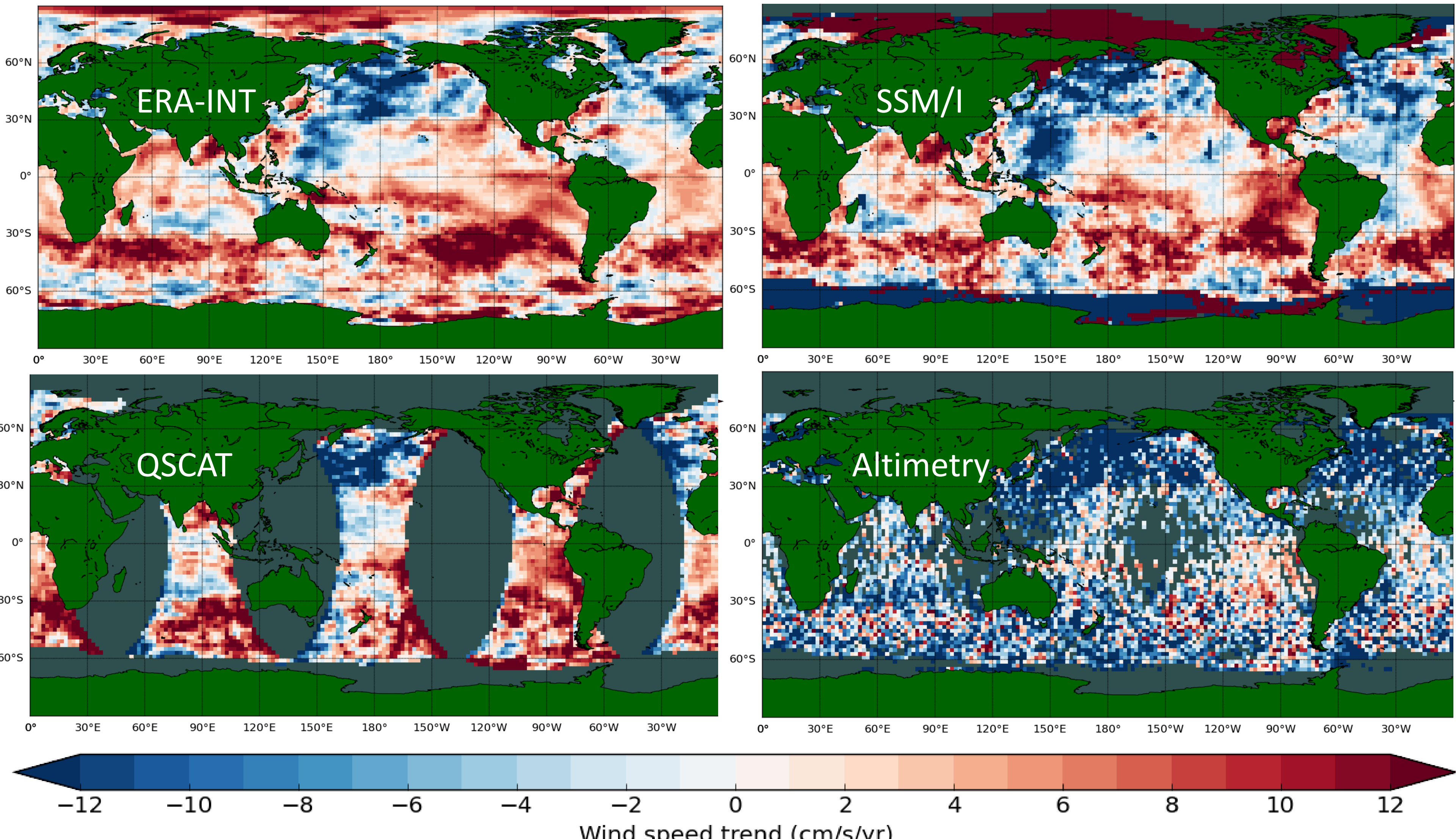
# 99th Percentiles

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